EVALUATION OF SELECTED INSTRUMENTS FOR MONITORING SCOUR AT BRIDGES IN NEW YORK

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Abstract Reliable methods to monitor scour at bridges are needed to ensure public safety and minimize the cost to repair or replace vulnerable bridges. The U.S. Geological Survey, in cooperation with the New York State Department of Transportation, is evaluating four instruments for the Federal Highway Administration's Demonstration Project 97, "Scour Monitoring and Instrumentation." The instruments include (1) a magnetic sliding collar developed in the National Cooperative Highway Research Program (NCHRP), (2) an NCHRP sonar system, (3) a commercial sonar and satellite telemetry (SST) system, and (4) a commercial multichannel sonar and telephone telemetry (MSTT) system.

The instruments were installed between August 1994 and February 1995 and were not damaged by ice or debris during the first year of operation. The reliability of the equipment requires further evaluation because the 1995 peak discharges were less than 50 percent of the mean-annual peak discharges at the study sites. Minor errors in the sliding-collar measurements resulted from accumulation of excess sensor cable at bends in the pipe. The errors between median sonar depths and field-measured depths ranged from 0.2 to 0.4 feet. Sonar data were adversely affected whenever a transducer was exposed to air, ice, or debris, or located less than the minimum distance from the streambed (1-2 feet). The MSTT system measured 0.4 feet of scour that developed during a 12-hour period beginning about 6 hours before the 1995 peak discharge.

Introduction Bridge failures in California during March 1995 reemphasize the dangers of scour noted in the 1987 collapse of the New York State Thruway bridge over Schoharie Creek. Streambeds at about 85,000 bridges in the United States are vulnerable to scour, and an additional 100,000 bridges have unknown foundations that must be monitored (Lagasse and others, 1995). The Federal government spent about $200 million to repair bridges damaged by floods during the 1980's. Repair costs in New York were about $7 million, and indirect costs to business and industry in New York were about $36 million (Rhodes and Trent, 1993). Reliable methods to monitor scour at bridges are needed to ensure public safety and minimize the cost to repair or replace vulnerable bridges.

The National Cooperative Highway Research Program (NCHRP) in 1989 began project 21-3, "Instrumentation for Measuring Scour at Bridge Piers and Abutments," to develop, test, and evaluate scour-monitoring instruments. Subsequently, the Federal Highway Administration (FHWA) developed Demonstration Project 97 (DP-97), "Scour Monitoring and Instrumentation," to promote new and innovative equipment that State and local highway departments can use to measure and monitor scour.

The U.S. Geological Survey (USGS), in cooperation with New York State Department of Transportation (NYSDOT), is evaluating four scour monitors for FHWA DP-97: (1) an NCHRP sliding collar, (2) an NCHRP sonar system, (3) a commercial sonar and satellite telemetry (SST) system, and (4) a commercial multichannel sonar and telephone telemetry (MSTT) system. Scour holes that were present before installation of the sliding collar, SST system, and MSTT system were backfilled with bed material by NYSDOT. Data collected from the instruments are being compared with field observations to verify spatial and temporal changes in streambed elevations.

This report describes the installation procedures and principles of operation for each instrument; it also describes the performance and accuracy of the equipment during the first year of monitoring.

Scour-Monitoring Instruments The reliability of a sliding collar and three sonars in New York's harsh stream environment is being evaluated in a 2-year study. The instruments were installed between August 1994 and February 1995, and methods to protect the equipment from ice and debris are also being evaluated. Further information on the design and operation of sonar systems are described by Mueller and Landers (1995), Hayes and Drummond (1995), and Crumrine (1992).

NCHRP Sliding Collar The NCHRP magnetic sliding collar (fig. 1) is a simple device that rests on the streambed and slides down a 2-in i.d. vertical stainless-steel pipe as the streambed is scoured beneath the collar. The sliding collar at State Route 30/145 over Schoharie Creek at Middleburg, N.Y. was installed in September 1994. Before installation, NYSDOT backfilled with sand, gravel, and cobbles a scour hole that partly exposed the footing, and used a drill rig to lower the

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stainless-steel pipe into a 10-ft. borehole at the upstream side of the footing. The collar (fig. 1) was mounted near the top of the stainless-steel pipe, about 25 ft. below the bridge deck and 0.5 ft. below the streambed. Schedule-40 galvanized pipe was attached to the stainless-steel pipe and was supported by a steel bracket at the base of the pier. Schedule-80 galvanized pipe was mounted to the upstream side of the pier from the steel bracket to the bridge deck. Rubber O-rings and a waterproof compound prevented seepage into the pipe. The distance from the top of the pipe to the collar was measured from the bridge deck by a sensor attached to the end of a 40-ft.-long graduated cable. The cable was inserted into the pipe until the sensor was adjacent to the magnetic collar and activated a buzzer.

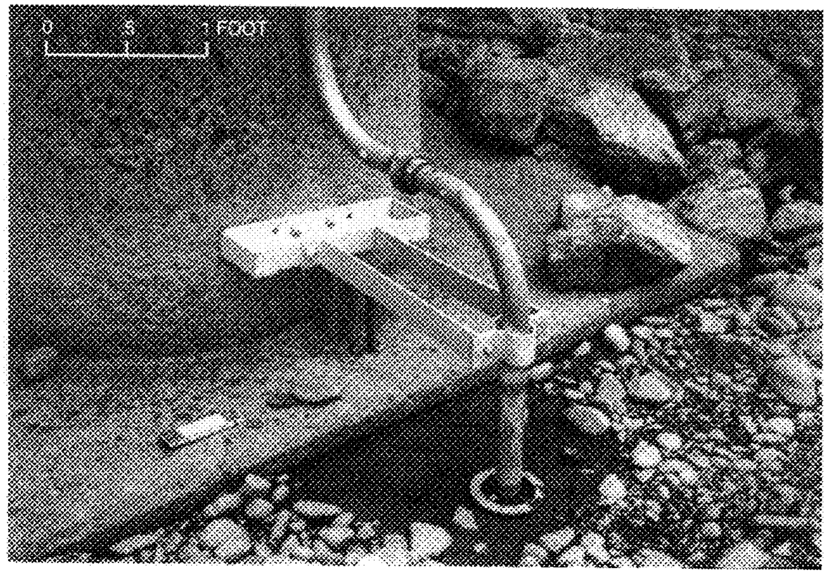

Figure 1. Sliding collar installed upstream of bridge pier at State Route 30/145 over Schoharie Creek at Middleburg, N.Y.

NCHRP Sonar An NCHRP sonar device was installed at State Route 418 over the Hudson River near Warrensburg, N.Y. in October 1994 to monitor the stability of rock installed by NYSDOT at the base of the pier. The device measures the time required for an 8°, 192-kHz acoustic pulse to travel from the transducer to the streambed and back. The range of the sonar signal is 2 to 100 ft., and the resolution is 0.1 ft. The traveltime of the reflected signal is converted into distance from the velocity of sound in freshwater at 60°F. The maximum distance that can be measured without exceeding an error of 1.0 ft. ranges from 30 ft. at 32°F to 40 ft. at 80°F (Schall and others, 1994).

A permanent shield was installed around the transducer by NYSDOT to protect the transducer and cable from ice and debris (fig. 2). The transducer was mounted 3 ft. from the streambed in a 4-in i.d. schedule-80 galvanized pipe angled 10° upstream from the pier. The pipe was angled upstream so that the signal path between the transducer and the streambed would be unobstructed by the pier footing. The transducer cable extended 270 ft. to an instrument shelter and was installed in a groove cut into the pier for added protection. A data logger activates the sonar at 1-hour intervals, processes the signal, and can store about 2 years of data. A portable computer and software provided by the manufacturer were used to program the data logger and retrieve data. The sonar and data logger are powered by a 12-V battery and solar panel. An internal battery maintains data storage if power is interrupted.

Sonar and Satellite Telemetry System A commercial SST system was installed at State Route 41 over the Susquehanna River at Afton, N.Y. in August 1994. The unit transmits an 8°, 200-kHz acoustic signal that is corrected by a microprocessor for variations in water temperature, false echoes, and ambient noise. The unit is a

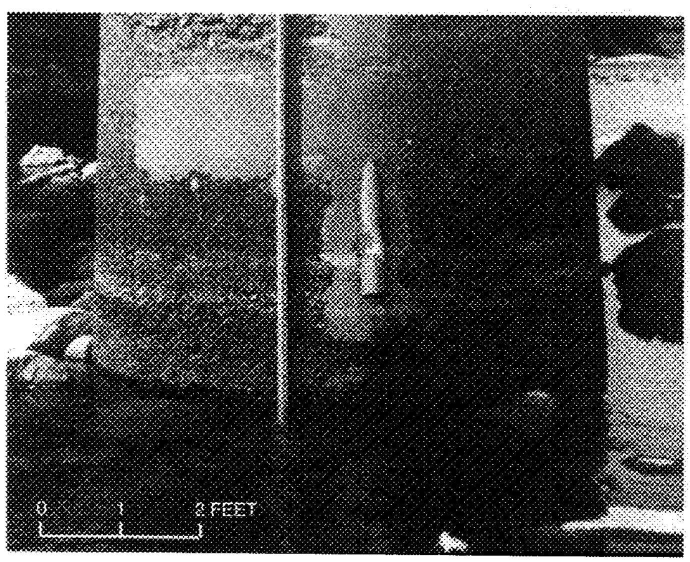

Figure 2. Protective shield for transducer mounted in bridge pier at State Route 418 over Hudson River near Warrensburg, N.Y.

modified version of a sonar system that was installed at another bridge during 1989-93 (Butch, 1991). The range is 1.0 to 10.0 ft., and the resolution is less than 0.1 ft.

The transducer was mounted in a 5-in i.d. pipe angled 22° upstream from the pier so that the signal path between the transducer and the streambed would be unobstructed by the pier footing (fig. 3). The transducer cable was protected from ice and debris by 2-in i.d. schedule-80 galvanized pipe and extended 300 ft. to an instrument shelter. A data-collection platform (DCP) activates the sonar at 1-hour intervals when the transducer is submerged, and at 24-hour intervals when the transducer is above the water surface. A portable computer was used to program the DCP, which transmitted data to the USGS by satellite telemetry every 4 hours. A scour hole at the upstream side of the pier was backfilled with bed material by NYSDOT in June 1995. The SST system is powered by a 24–V battery and a regulator charger.

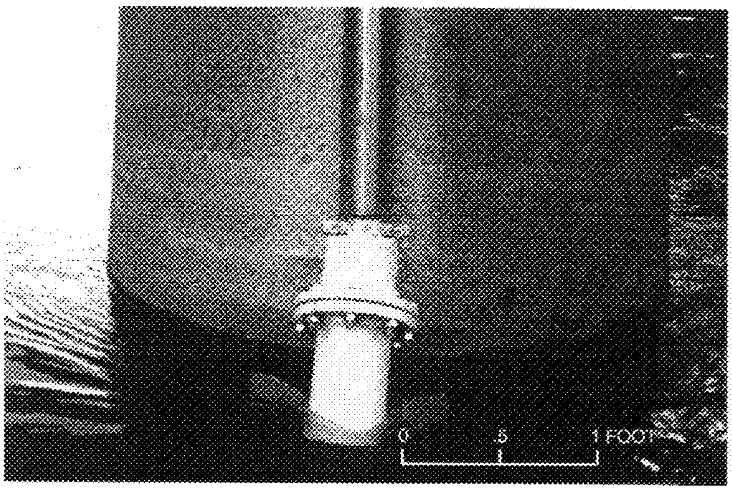

Figure 3. Protective shield for transducer mounted onto bridge pier at State Route 41, over Susquehanna River at Afton, N.Y.

Multichannel Sonar and Telephone Telemetry System A commercial MSTT system was installed at State Route 23 over the Otselic River at Cincinnatus, N.Y. in February 1995 (fig. 4). The unit transmits an 8°, 200-kHz acoustic signal at 15-minute intervals. The range is 1.0 to 32.8 ft., and the resolution is less than 0.1 ft. The streambed was monitored at four locations around the pier because (1) high flows lowered the streambed about 8 ft. at the upstream (northern) side of the pier during 1981-94, (2) a 30° angle between the flow and the pier extended the scour hole along the western side of the pier, and (3) a mobile gravel bar was observed at the eastern and southern sides of the pier (Butch, 1993, 1994).

NYSDOT graded the streambed and backfilled the scour holes with sand and gravel before installation of the MSTT system in 1994. Four transducers were installed around the pier to measure the distance from the footing to the streambed; a fifth transducer was inverted at the western side of the pier to measure the distance from the footing to the water surface. Shields and 2-in i.d. schedule-40 galvanized pipe were installed to protect the transducers and cables from ice and debris. The cables extended 200 ft. to an instrument shelter, where the MSTT system can store about 3 months of data. A portable computer and software provided by the manufacturer were used to program the unit and retrieve data. A modem was used for remote interrogation. The unit is powered by a 24-V battery and a regulator charger. An internal battery maintains data storage for about 90 days if power is interrupted.

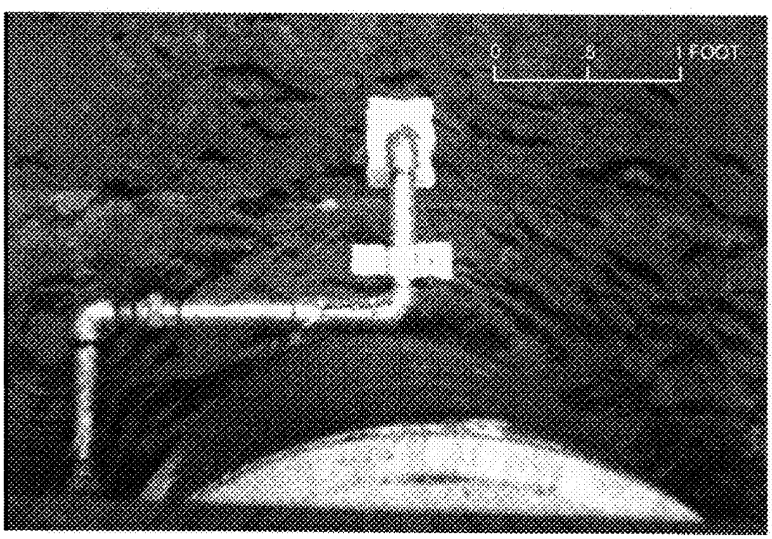

Figure 4. Protective shield for transducer mounted onto pier footing at State Route 23, over Otselic River at Cincinnatus, N.Y. (viewed from above).

Instrument Performance None of the scour monitors were damaged by ice or debris during the first year of operation. The reliability of the equipment needs further evaluation, however, because the 1995 peak discharges were less than 50 percent of the mean-annual peak discharges at the study sites.

NCHRP Sliding Collar The distance from the top of the pipe to the collar ranged from 28.8 to 29.0 ft. during the four inspections at State Route 30/145 over Schoharie Creek in the 1995 water year. The range between measurements resulted from accumulation of excess cable at two bends in the pipe as the sensor was lowered to the magnetic collar. The July inspection found the collar to be uncovered but not undermined; this could have occurred during peak stages in January or March, as indicated by gage-height data 7 mi upstream at Breakabeen (USGS station 01350355) (fig. 5).

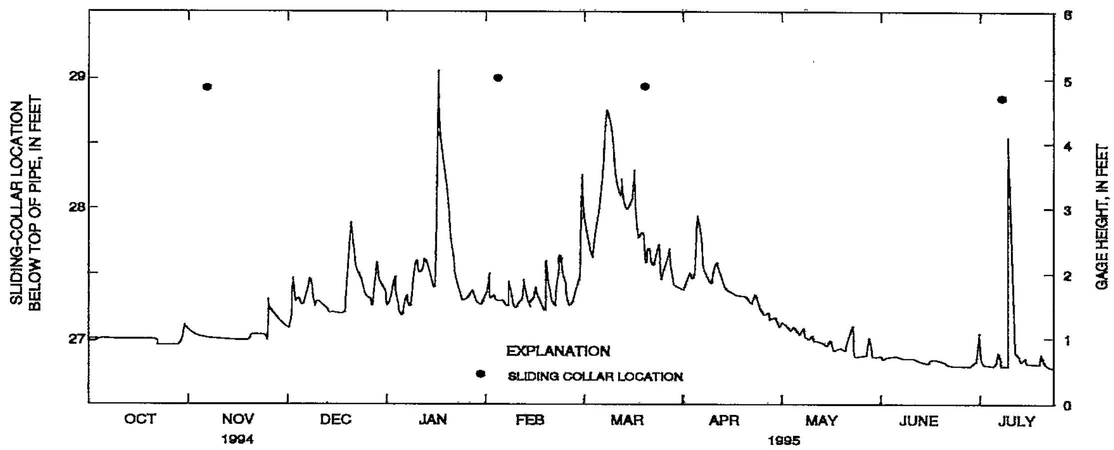

Figure 5. NCHRP sliding-collar measurements at State Route 30/145, and gage height at Schoharie Creek at Breakabeen, N.Y. (01350355), October 1994 through July 1995.

The cable used to position the collar broke during shipment and was cumbersome to store; also, it stiffened in cold temperatures. A newer version of the sliding collar does not use a graduated cable and can be connected to a data logger; it also may be less vulnerable to ice and debris than the model tested because the sensor cable can be mounted to the downstream side of the pier.

NCHRP Sonar The NCHRP sonar at State Route 418 over the Hudson River performed well after the measurement time was increased from 20 seconds to 45 seconds in March 1995. The site was inspected nine times during the 1995 water year, and no scour was observed. The field-measured distance between the transducer and the streambed ranged from 2.8 to 3.0 ft., and the median sonar depth ranged from 3.0 to 3.2 ft. (fig. 6). The transducer is submerged whenever the gage height at Hadley, 13 mi downstream (USGS station 01318500), exceeds about 4 feet (fig. 6). No data were recorded when the transducer was above the water surface or surrounded by ice.

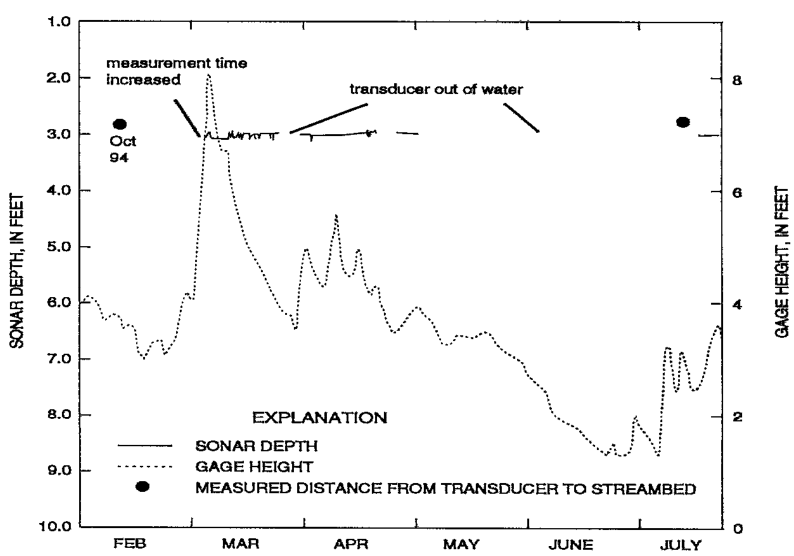

Figure 6. Sample NCHRP sonar depth and measured distance at State Route 418, and gage height at Hudson River at Hadley, N.Y. (01318500), February through July 1995.

No sonar data were collected from October 1994 through March 1995 because the 20-second measurement time that was programmed in the data logger was too short to activate the sonar and compute an average depth. A 45-second measurement time was ample to process the signal; it also improved streambed detection when floating ice momentarily obstructed the signal path. The other processing routines in the data logger include (1) activation of the sonar at 1-hour intervals, (2) computation of an average depth if the difference between three depth readings is 0.3 ft. or less, (3) the recording of a "no lock" condition when an echo is not received, and (4) the recording of an "outside limits" condition if an average depth cannot be computed within the programmed measurement time. The 270-ft.-long transducer cable and the 10° transducer angle did not adversely affect the signal because the shallow depth and solid streambed minimize signal attenuation. Despite a malfunctioning relay, the solar panel provided adequate power at -20°F to maintain continuous operation of the sonar.

<u>Sonar and Satellite Telemetry System</u> The commercial SST system at State Route 41 over the Susquehanna River operated with few problems. The site was inspected five times during the 1995 water year, and no scour was observed. NYSDOT backfilled the scour hole with bed material in June 1995; as a result, the field-measured distance between the transducer and the streambed decreased from 3.8 ft. to 1.7 ft., and the median sonar depth decreased from 4.2 ft. to 2.1 ft. (fig. 7). The transducer gave inaccurate data when exposed to air or ice and became submerged whenever the gage height 50 ft. downstream at Afton (USGS station 01502701) exceeded about 2 ft. Debris attached to a submerged log resulted in occasional spikes in the data until the log was removed in June 1995 (fig. 7). Minor signal scatter is attributed to wide reflections from cobbles. The 22° transducer angle and the 300-ft. length of the cable did not adversely affect the data, although the cable length increased signal noise.

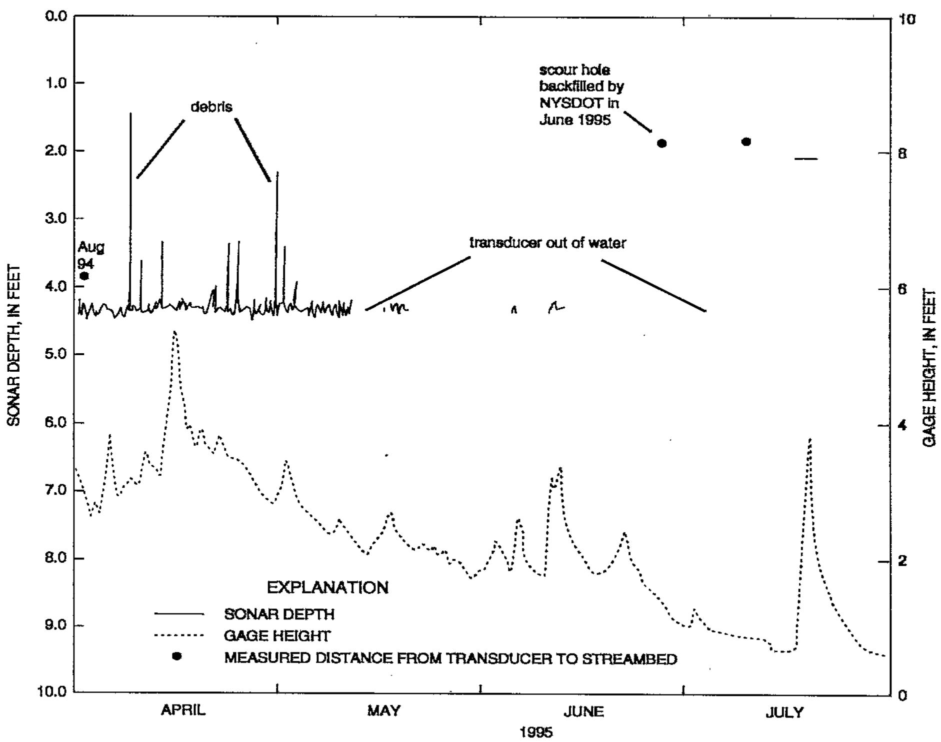

Figure 7. Example Sonar and Satellite Telemetry System sonar depth and measured distance at State Route 41, and gage height at Susquehanna River at Afton, N.Y. (01502701), April through July 1995.

<u>Multichannel Sonar and Telephone Telemetry System</u> The commercial MSTT system at State Route 23 over the Otselic River performed well, except when the distance between the transducer and the streambed was less than about 1 ft. (the minimum range of the sonar). The site was inspected three times during the 1995 water year. The field-measured distance between the streambed and the transducer at the upstream (northern) side of the pier in February 1995 was 1.3 ft., and the median sonar depth was 1.0 ft. The median sonar depth increased to 1.4 ft. during the 1995 peak discharge in March (fig. 8), and the field-measured distance increased to 1.6 ft. Scour began about 6 hours before the peak and continued for about 12 hours (fig. 9). Median sonar depth and field-measured distance had decreased about 0.4 ft. by July, possibly the result of low flows and (or) adjustment of the graded streambed to an equilibrium elevation. Signal scatter increased in March as the scour hole deepened and the local slope of the streambed increased. Scour may have occurred April 4 or April 13 but debris degraded the signal from the transducer. New software corrected a modem problem that resulted in loss of data for 3 days during March. The number of multiple echoes increased during June and July as the distance between the transducer and streambed decreased.

The sonar depths measured by the transducers mounted on the western and southern sides of the pier are unreliable because the distance to the streambed is less than 1.0 ft. The transducer mounted on the eastern side of the pier was found buried by a gravel bar in April. The two transducers mounted on the western side of the pier were shifted by ice or debris. Gage-height data less than 1 mi upstream at Cincinnatus (USGS station 01510000) were used to supplement the sonar data because turbulence and debris had degraded the signal from the transducer aimed upward at the water surface.

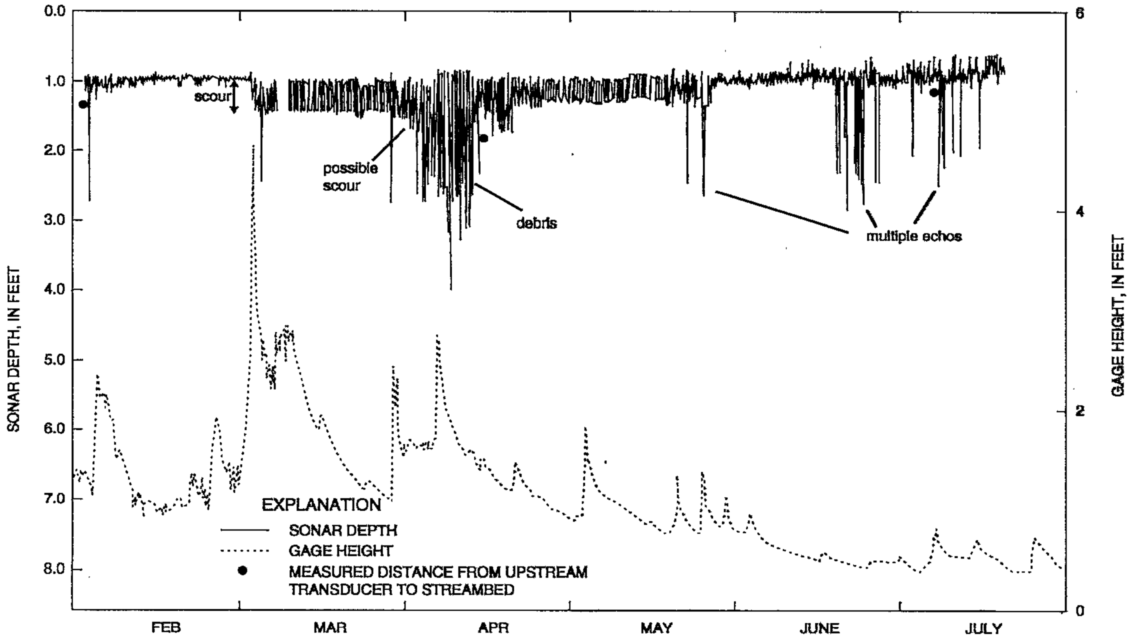

Figure 8. Multichannel Sonar and Telephone Telemetry System sonar depth and measured distance at State Route 23, and gage height at Otselic River at Cincnnatus, N.Y. (01510000), February 1995 through July 1995.

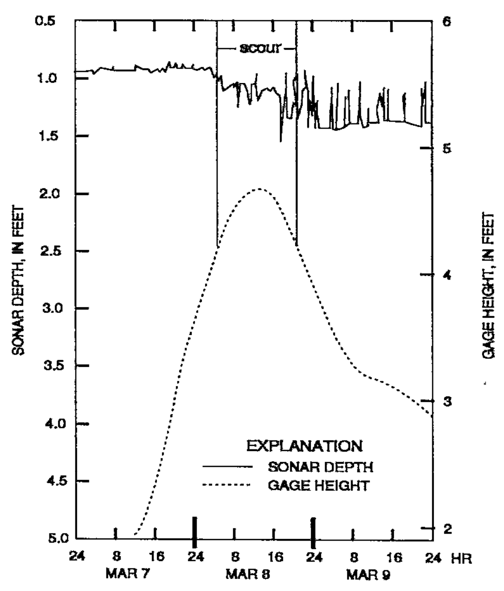

Figure 9. Multichannel Sonar and Telephone Telemetry System sonar depth at State Route 23 and gage height at Otselic River at Cincinnatus, N.Y. (01510000), March 7-9, 1995.

Summary Four types of scour-monitoring instruments are being evaluated for FHWA Demonstration Project 97, "Scour Monitoring and Instrumentation": (1) an NCHRP sliding collar, (2) an NCHRP sonar system, (3) a commercial sonar and satellite telemetry (SST) system, and (4) a commercial multichannel sonar and telephone telemetry (MSTT) system. The instruments were installed between August 1994 and February 1995 and were not damaged by ice or debris during the first year of operation. The reliability of the equipment needs to be evaluated during flows higher than 1995 peak flows, which were less than 50 percent of the mean-annual peak discharges at the study sites. Scour holes that were present before the study began were backfilled with bed material by NYSDOT. Sonar data were adversely affected whenever a transducer was exposed to air, ice, or debris, or located less than the minimum distance from the streambed (1-2 ft.).

The NCHRP sliding collar was installed in September 1994 and did not indicate any scour. Minor measurement errors resulted from accumulation of excess sensor cable at bends in the pipe. A newer version of the collar does not require a graduated cable and can be connected to a data logger; it also may be less vulnerable to ice and debris than the model tested.

The NCHRP sonar system performed well after the measurement time was increased from 20 seconds to 45 seconds in March 1995. Median sonar depths were within 0.2 ft. of measured distances. The processing routines identified inaccurate data that resulted from the transducer's exposure to air or ice, but other errors were occasionally recorded when the transducer was partly submerged. A portable computer is needed to program the data logger and retrieve data.

The commercial SST system has performed well since the unit was installed in August 1994, although it has indicated no scour. Median sonar depths were within 0.4 ft. of measured distances. Inaccurate data were collected whenever the transducer was exposed to air, ice, or debris. A DCP activates the sonar at 1-hour intervals when the transducer is submerged and at 24 hour intervals when the transducer is above the water surface. Data are transmitted to the USGS by satellite telemetry every 4 hours.

The commercial MSTT system has operated with no major problems. The median sonar depths were within 0.3 ft. of the measured distances at the upstream side of the pier. The unit measured 0.4 ft. of scour during the 1995 peak discharge. The scour started about 6 hours before the peak and continued for about 12 hours. Sonar depths from three other transducers mounted around the pier are unreliable because the distance between each transducer and the streambed is less than 1.0 ft., the minimum range of the unit. Turbulence and debris affected a fifth transducer that measures the distance from the pier footing to the water surface. A portable computer and modem were used to program the unit and retrieve data.

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